coastalmanagement

Shag Estuary

Fine Scale Monitoring 2016/17

Prepared for

Otago Regional Council

May 2017

Cover Photo: Shag Estuary lower reaches


Shag Estuary middle reaches

Shag Estuary

Fine Scale Monitoring 2016/17

Prepared for
Otago Regional Council

by

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SHAG ESTUARY - EXECUTIVE SUMMARY

This report summarises the results of the first year of fine scale baseline monitoring (2016) of two benthic intertidal sites and three water column sites within Shag Estuary, a moderate sized, shallow, intertidal dominated (SIDE) estuary on the Otago coast. It is one of the key estuaries in Otago Regional Council's (ORC's) long-term coastal monitoring programme. The following table summarises the fine scale monitoring results, risk indicator ratings, overall estuary condition, and monitoring recommendations.

FINE SCALE BENTHIC MONITORING RESULTS

Benthic Intertidal Results

- There was no seagrass and <5% cover of opportunistic macroalgae at both sites.
- Sediment mud content was moderate (19-23% mud) with the lowest content at Site A nearest the ocean.
- Sediment oxygenation was poor at both sites (redox potential <-150mV below 0.5cm depth).
- The indicators of organic enrichment (total organic carbon) and nutrient enrichment (total nitrogen and phosphorus) were at low concentrations.
- The estuary macroinvertebrate community index (NZ HybAMBI) indicated an unbalanced community affected by elevated mud concentrations and poor oxygenation.

Water Column Results

- The salinity results for the surface and bottom waters of the three sites shows that the mid to upper estuary was stratified with saline bottom water overlain by a freshwater influenced less dense saline layer at both mid estuary site Y and upper estuary site Z. The presence of isolated (stratified) bottom water where nutrient concentrations can build-up indicates a high potential for eutrophication symptoms to develop.
- Total nitrogen (TN) concentrations exceeded the eutrophication threshold of $0.4mgl^{-1}$ in the upper-mid estuary bottom layer, but not at the other sites.
- Chlorophyll *a* concentrations, the primary indicator of water column eutrophication, exceeded the NZ ETI eutrophication threshold level of $16ugl^{-1}$. Bottom water at upper Site Z had a very high concentration (i.e. $227ugl^{-1}$ chlorophyll *a*) while the lower estuary, and the surface waters at the upper and middle sites, had low concentrations.

BENTHIC RISK INDICATOR RATINGS
(INDICATE RISK OF ADVERSE ECOLOGICAL IMPACTS)

	Low		Moderate
	Very Low		High

Shag Estuary	Site Shag A (lower basin)				Site Shag B (upper basin)			
	2016	Yr 2	Yr 3	Yr 4	2016	Yr 2	Yr 3	Yr 4
Sediment Mud Content								
Redox Potential (Oxygenation)								
TOC (Total Organic Carbon)								
Total Nitrogen								
Invertebrate Mud/Org Enrichment								
Metals (Cd, Cu, Cr, Hg, Ni, Pb, Zn As)								

ESTUARY CONDITION AND ISSUES

Benthic Habitat

The fine scale monitoring of representative intertidal sediments showed the presence of muddy, poorly-oxygenated sediments, with an unbalanced macroinvertebrate community despite the estuary having low organic and nutrient concentrations and low macroalgal cover. Such findings are relatively atypical of NZ SIDE estuaries in that muddy, poorly oxygenated intertidal sediments were located in close proximity to the estuary mouth.

Shag Estuary - Executive Summary (continued)

Water Column Habitat

Taken as a whole, the December 2016 data showed that the bottom water in the middle and upper estuary was stratified and eutrophic, as indicated by very high chlorophyll *a* and ammonia concentrations and the presence of TN exceeding the eutrophication threshold concentration. The data also showed that the remainder of the estuary had a low susceptibility to water column eutrophication and no indication of phytoplankton blooms. However, given only one comprehensive sampling event, questions remain around likely duration, magnitude and frequency of such eutrophication symptoms. Although upper estuary bottom water stratification is a natural event in many shallow NZ estuaries, it can be exacerbated by reductions in natural river inflows (e.g. from upstream water abstraction and damming). Once established, the extent of eutrophication in the bottom layer is likely to be primarily driven by catchment nutrients, particularly nitrogen. Preliminary indications suggest that river total nitrogen inputs would need to be much less than $0.4mgNl^{-1}$ in order to minimise eutrophication symptoms in this sensitive zone of the estuary.

Overall, the findings indicate that muddiness, and upper estuary bottom-water phytoplankton blooms, are issues that require further attention.

RECOMMENDED MONITORING

Shag Estuary has been identified by ORC as a priority for monitoring because it is a moderate sized estuary with high ecological and human use values that is situated in a developed catchment, and therefore vulnerable to excessive sedimentation and eutrophication. In order to assess ongoing long-term trends in the condition of such estuaries, it is common practice amongst NZ Regional Councils to establish a strong baseline against which future trends can be compared. This typically comprises comprehensive broad scale habitat mapping on a 5-10 yearly cycle, targeted monitoring where specific issues are identified (e.g. opportunistic nuisance macroalgal growth), and fine scale monitoring comprising 3-4 consecutive years of baseline monitoring, followed by 5 yearly impact monitoring.

Broad scale habitat mapping and fine scale sampling has now been undertaken for 1 baseline year (December 2016). To complete the fine scale baseline in Shag Estuary, it is recommended that 3 consecutive years of annual summer (i.e. Dec-Feb) fine scale monitoring of intertidal sites (including sedimentation rate measures), and water column monitoring, be undertaken in 2017, 2018 and 2019.

Turbid waters of upper -mid Shag Estuary during low flows, indicative of elevated fine sediment inputs

1. INTRODUCTION

Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. The Otago Regional Council's 'Regional Policy Statement and Regional Plan: Water' demonstrates the Council's determination to maintain estuaries in good condition. In the period 2005-2008 Otago Regional Council (ORC) undertook preliminary (one-off) monitoring of the condition of seven Otago estuaries in its region. In 2016, ORC began a more comprehensive long-term estuary monitoring programme designed to particularly address the key NZ estuary issues of eutrophication and sedimentation within their estuaries, as well as identifying any toxicity and habitat change issues. The estuaries currently included in the programme are; Shag Estuary, Waikouaiti Estuary and Catlins Estuary.

Monitoring of the Shag Estuary began with preliminary broad and fine scale monitoring undertaken on 23 November 2006 and the first year of comprehensive baseline monitoring undertaken in December 2016.

Within NZ, the approach for monitoring estuary condition follows the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002) and the NZ Estuary Trophic Index (ETI) (Robertson et al. 2016a and b). It consists of three components as follows:

1. **Ecological Vulnerability Assessment (EVA**) of estuaries in the region to major issues (see Table 1) and appropriate monitoring design. This component has not yet been undertaken on a regional scale for Otago and hence relative vulnerabilities of their estuaries to the key issues have not been formally identified.
2. **Broad Scale Habitat Mapping (NEMP approach).** This component (see Table 1) maps the key habitats within the estuary, determines their condition, and assesses changes to these habitats over time. Broad scale intertidal mapping of Shag Estuary was first undertaken in November 2006 (Stewart 2007) and was repeated in December 2016 (Stevens and Robertson 2017).
3. **Fine Scale Monitoring (NEMP approach).** Monitoring of physical, chemical and biological indicators (see Table 1). This component, which provides detailed information on the condition of Shag Estuary, was undertaken in a partial form in November 2006 (Stewart 2007), with the first year of baseline monitoring undertaken on 9 December 2016. This latter monitoring is the subject of this report.

To help evaluate overall estuary condition and decide on appropriate monitoring and management actions, a series of risk indicator ratings are presented and described in Section 2. The current report describes the 2016 fine scale results and compares them to the previous findings.

Shag Estuary

The Shag Estuary is a moderate-sized (120ha), shallow, intertidal dominated estuary (SIDE) on the Otago east coast (Figure 1). It comprises a mix of several confined upper estuary river channels, a large central basin, two small side arm basins, and a 600m long sand spit on the southern coastal margin that creates a narrow entrance to the estuary. The tidal estuary extends ~3km up the valley with its margins lined by high-tidal saltmarsh and historically included large areas of estuary or flood plain but which have subsequently been developed for farming. The greatest development has occurred on the southern and western sides of the estuary. The Shag Estuary is listed as a coastal protection area in the Regional Plan: Water (see Section 3.0). The estuary has Kai Tahu cultural and spiritual values, and its estuarine values include large mudflats used as feeding and roosting areas for birds, fish nursery habitat, and whitebait spawning int he upper tidal reaches.

Catchment landuse is dominated by sheep and beef grazing on high and low producing exotic grassland but it also includes significant areas of exotic forest. However, because the catchment is hilly in nature, contains soft rock types, and is primarily grazed, the suspended sediment yield is elevated. As a consequence, the estuary receives excessive inputs of fine sediments and the water is relatively turbid, and the bed muddy except for the very lowest reaches where firm sands/gravels dominate.

Because the estuary is fed by a relatively small river, the Shag (mean flow ~2.5m^3.s^{-1}), the main channel of the upper-mid estuary is poorly flushed during baseflows. As a consequence, this section becomes stratified with a surface layer of lighter, low salinity freshwater flowing over a layer of dense saline water. Because the dense bottom water layer is more stagnant, its water quality can deteriorate, particularly in relation to excessive inputs of nutrients (eutrophication) and fine muds.

Table 1. Summary of the major environmental issues affecting most New Zealand estuaries.

1. Sediment Changes

Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. Prior to European settlement they were dominated by sandy sediments and had low sedimentation rates (<1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, New Zealand's estuaries have begun to infill rapidly with fine sediments. Today, average sedimentation rates in our estuaries are typically 10 times or more higher than before humans arrived (e.g. see Abrahim 2005, Gibb and Cox 2009, Robertson and Stevens 2007a, 2010b, and Swales and Hume 1995). Soil erosion and sedimentation can also contribute to turbid conditions and poor water quality, particularly in shallow, wind-exposed estuaries where re-suspension is common. These changes to water and sediment result in negative impacts to estuarine ecology that are difficult to reverse. They include:

- habitat loss such as the infilling of saltmarsh and tidal flats,
- prevention of sunlight from reaching aquatic vegetation such as seagrass meadows,
- increased toxicity and eutrophication by binding toxic contaminants (e.g. heavy metals and hydrocarbons) and nutrients,
- a shift towards mud-tolerant benthic organisms which often means a loss of sensitive shellfish (e.g. pipi) and other filter feeders; and
- making the water unappealing to swimmers.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Sedimentation	Soft Mud Area	GIS Based Broad scale mapping - estimates the area and change in soft mud habitat over time.
	Seagrass Area/Biomass	GIS Based Broad scale mapping - estimates the area and change in seagrass habitat over time.
	Saltmarsh Area	GIS Based Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
	Mud Content	Grain size - estimates the % mud content of sediment.
	Water Clarity/Turbidity	Secchi disc water clarity or turbidity.
	Sediment Toxicants	Sediment heavy metal concentrations (see toxicity section).
	Sedimentation Rate	Fine scale measurement of sediment infilling rate (e.g. using sediment plates).
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in $0.0133m^2$ replicate cores), and on the sediment surface (epifauna in $0.25m^2$ replicate quadrats).

2. Eutrophication

Eutrophication is a process that adversely affects the high value biological components of an estuary, in particular through the increased growth, primary production and biomass of phytoplankton, macroalgae (or both); loss of seagrass, changes in the balance of organisms; and water quality degradation. The consequences of eutrophication are undesirable if they appreciably degrade ecosystem health and/or the sustainable provision of goods and services (Ferriera et al. 2011). Susceptibility of an estuary to eutrophication is controlled by factors related to hydrodynamics, physical conditions and biological processes (National Research Council, 2000) and hence is generally estuary-type specific. However, the general consensus is that, subject to available light, excessive nutrient input causes growth and accumulation of opportunistic fast growing primary producers (i.e. phytoplankton and opportunistic red or green macroalgae and/or epiphytes - Painting et al. 2007). In nutrient-rich estuaries, the relative abundance of each of these primary producer groups is largely dependent on flushing, proximity to the nutrient source, and light availability. Notably, phytoplankton blooms are generally not a major problem in well flushed estuaries (Valiela et al. 1997), and hence are not common in the majority of NZ estuaries. Of greater concern are the mass blooms of green and red macroalgae, mainly of the genera *Cladophora, Ulva,* and *Gracilaria* which are now widespread on intertidal flats and shallow subtidal areas of nutrient-enriched New Zealand estuaries. They present a significant nuisance problem, especially when loose mats accumulate on shorelines and decompose, both within the estuary and adjacent coastal areas. Blooms also have major ecological impacts on water and sediment quality (e.g. reduced clarity, physical smothering, lack of oxygen), affecting or displacing the animals that live there (Anderson et al. 2002, Valiela et al. 1997).

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Eutrophication	Macroalgal Cover/Biomass	Broad scale mapping - macroalgal cover/biomass over time.
	Phytoplankton (water column)	Chlorophyll *a* concentration (water column).
	Sediment Organic and Nutrient Enrichment	Chemical analysis of sediment total nitrogen, total phosphorus, and total organic carbon concentrations.
	Water Column Nutrients	Chemical analysis of various forms of N and P (water column).
	Redox Profile	Redox potential discontinuity profile (RPD) using visual method (i.e. apparent Redox Potential Depth - aRPD) and/or redox probe. Note: Total Sulphur is also currently under trial.
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in $0.0133m^2$ replicate cores), and on the sediment surface (epifauna in $0.25m^2$ replicate quadrats).

Table 1. Summary of major environmental issues affecting New Zealand estuaries (continued).

3. Disease Risk

Runoff from farmland and human wastewater often carries a variety of disease-causing organisms or pathogens (including viruses, bacteria and protozoans) that, once discharged into the estuarine environment, can survive for some time (e.g. Stewart et al. 2008). Every time humans come into contact with seawater that has been contaminated with human and animal faeces, we expose ourselves to these organisms and risk getting sick. Human diseases linked to such organisms include gastroenteritis, salmonellosis and hepatitis A (Wade et al. 2003). Aside from serious health risks posed to humans through recreational contact and shellfish consumption, pathogen contamination can also cause economic losses due to closed commercial shellfish beds.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Disease Risk	Shellfish and Bathing Water faecal coliforms, viruses, protozoa etc.	Bathing water and shellfish disease risk monitoring (Council or industry driven).

4. Toxic Contamination

In the last 60 years, NZ has seen a huge range of synthetic chemicals introduced to the coastal environment through urban and agricultural stormwater runoff, groundwater contamination, industrial discharges, oil spills, antifouling agents, leaching from boat hulls, and air pollution. Many of them are toxic even in minute concentrations, and of particular concern are polycyclic aromatic hydrocarbons (PAHs), heavy metals, polychlorinated biphenyls (PCBs), endocrine disrupting compounds, and pesticides. When they enter estuaries these chemicals collect in sediments and bio-accumulate in fish and shellfish, causing health risks to marine life and humans. In addition, natural toxins can be released by macroalgae and phytoplankton, often causing mass closures of shellfish beds, potentially hindering the supply of food resources, as well as introducing economic implications for people depending on various shellfish stocks for their income. For example, in 1993, a nationwide closure of shellfish harvesting was instigated in NZ after 180 cases of human illness following the consumption of various shellfish contaminated by a toxic dinoflagellate, which also lead to wide-spread fish and shellfish deaths (de Salas et al. 2005). Decay of organic matter in estuaries (e.g. macroalgal blooms) can also cause the production of sulphides and ammonia at concentrations exceeding ecotoxicity thresholds.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Toxins	Sediment Contaminants	Chemical analysis of heavy metals (total recoverable cadmium, chromium, copper, nickel, lead and zinc) and any other suspected contaminants in sediment samples.
	Biota Contaminants	Chemical analysis of suspected contaminants in body of at-risk biota (e.g. fish, shellfish).
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in $0.0133m^2$ replicate cores), and on the sediment surface (epifauna in $0.25m^2$ replicate quadrats).

5. Habitat Loss

Estuaries have many different types of high value habitats including shellfish beds, seagrass meadows, saltmarshes (rushlands, herbfields, reedlands etc.), tidal flats, forested wetlands, beaches, river deltas, and rocky shores. The continued health and biodiversity of estuarine systems depends on the maintenance of high-quality habitat. Loss of such habitat negatively affects fisheries, animal populations, filtering of water pollutants, and the ability of shorelines to resist storm-related erosion. Within New Zealand, habitat degradation or loss is common-place with the major causes being sea level rise, population pressures on margins, dredging, drainage, reclamation, pest and weed invasion, reduced flows (damming and irrigation), over-fishing, polluted runoff, and wastewater discharges (IPCC 2007 and 2013, Kennish 2002).

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Habitat Loss	Saltmarsh Area	Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
	Seagrass Area	Broad scale mapping - estimates the area and change in seagrass habitat over time.
	Vegetated Terrestrial Buffer	Broad scale mapping - estimates the area and change in buffer habitat over time.
	Shellfish Area	Broad scale mapping - estimates the area and change in shellfish habitat over time.
	Unvegetated Habitat Area	Broad scale mapping - estimates the area and change in unvegetated habitat over time, broken down into the different substrate types.
	Sea level	Measure sea level change.
	Others e.g. Freshwater Inflows, Fish Surveys, Floodgates, Wastewater Discharges	Various survey types.

2. ESTUARY RISK INDICATOR RATINGS

The estuary monitoring approach used by Wriggle has been established to provide a defensible, cost-effective way to help quickly identify the likely presence of the predominant issues affecting NZ estuaries (i.e. eutrophication, sedimentation, disease risk, toxicity, and habitat change; Table 1), and to assess changes in the long term condition of estuarine systems. The design is based on the use of primary indicators that have a documented strong relationship with water or sediment quality.

In order to facilitate this assessment process, "risk indicator ratings" have also been proposed that assign a relative level of risk (e.g. very low, low, moderate, high) of specific indicators adversely affecting intertidal estuary condition (see Table 2 below). Each risk indicator rating is designed to be used in combination with relevant information and other risk indicator ratings, and under expert guidance, to assess overall estuarine condition in relation to key issues, and make monitoring and management recommendations. When interpreting risk indicator results we emphasise:

- The importance of considering other relevant information and/or indicator results before making management decisions regarding the presence or significance of any estuary issue.
- That rating and ranking systems can easily mask or oversimplify results. For instance, large changes can occur within the same risk category, but small changes near the edge of one risk category may shift the rating to the next risk level.
- Most issues will have a mix of primary and secondary ratings, primary ratings being given more weight in assessing the significance of indicator results. It is noted that many secondary estuary indicators will be monitored under other programmes and can be used if primary indicators reflect a significant risk exists, or if risk profiles have changed over time.
- Ratings have been established in many cases using statistical measures based on NZ and overseas data and presented in the NZ Estuary Trophic Index (NZ ETI; Robertson et al. 2016a and 2016b). However, where such data is lacking, or has yet to be processed, ratings have been established using professional judgement, based on our experience from monitoring numerous NZ estuaries. Our hope is that where a high level of risk is identified, the following steps are taken:
  - Statistical measures be used to refine indicator ratings where information is lacking.
  - Issues identified as having a high likelihood of causing a significant change in ecological condition (either positive or negative), trigger intensive, targeted investigations to appropriately characterise the extent of the issue.
  - The outputs stimulate discussion regarding what the acceptable level of risk is, and managing it.
  - The indicators and condition ratings used for the Shag monitoring programme are summarised in Table 2, with detailed background notes explaining the use and justifications for each indicator presented in the NZ ETI (Robertson et al. 2016a and 2016b). The basis underpinning most of the ratings is the observed correlation between an indicator and the presence of degraded estuary conditions from a range of NZ estuaries. Work to refine and document these relationships is ongoing.

Table 2. Summary of relevant estuary condition risk indicator ratings used in the present report.

RISK INDICATOR RATINGS / ETI BANDS (indicate risk of adverse ecological impacts)				
INDICATOR	Very Low - Band A	Low - Band B	Moderate - Band C	High - Band D
Apparent Redox Potential Discontinuity (aRPD)**	Unreliable	Unreliable	0.5-2cm	<0.5cm
Redox Potential (mV) upper 3cm***	>+100	-50 to +100	-50 to -150	<-150
Sediment Mud Content (%mud)*	<5%	5-10%	>10-25%	>25%
Macroinvertebrate Enrichment Index (NZ AMBI) ******	0-1.0 None to minor stress on benthic fauna	>1.0-2.5 Minor to moderate stress on fauna	>2.5-4.0 Moderate to high stress on fauna	>4.0 Persistent, high stress on benthic fauna
Total Organic Carbon (TOC)*	<0.5%	0.5-<1%	1-<2%	>2%
Total Nitrogen (TN)*	<250mg/kg	250-1000 mg/kg	>1000-2000 mg/kg	>2000 mg/kg
Metals	<0.2 x ISQG Low	0.2 - 0.5 x ISQG Low	0.5 x to ISQG Low	>ISQG Low

* NZ ETI (Robertson et al. 2016b), ** and *** Hargrave et al. (2008), ***Robertson (in prep.), Keeley et al. (2012), **** Robertson et al. (2016).

3. METHODS

FINE SCALE MONITORING

Fine scale monitoring is based on the methods described in the National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002), and subsequent extensions (e.g. Robertson et al. 2016b) and provides detailed information on indicators of chemical and biological condition of the dominant habitat type in the estuary. This is most commonly unvegetated intertidal mudflats at low-mid water (avoiding areas of significant vegetation and channels). In addition, because some SIDE estuaries also include subtidal habitat that is at risk from eutrophication and sedimentation (e.g. deep stratified areas or main channel sections in estuaries where the mouth is restricted), synoptic water quality samples from surface and bottom waters, and subtidal sediment are commonly collected to support intertidal assessments.

Using the outputs of the broad scale habitat mapping, representative intertidal sampling sites (usually two per estuary, but varies with estuary size) are selected and samples collected and analysed for the following variables.

- Salinity, Oxygenation (Redox Potential Discontinuity depth - aRPD or RPmV), Grain size (% mud, sand, gravel).
- Organic Matter and Nutrients: Total Organic Carbon (TOC), Total Nitrogen (TN), Total Phosphorus (TP).
- Heavy metals and metalloids: Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Nickel (Ni), and Zinc (Zn) plus mercury (Hg) and arsenic (As). Analyses are based on non normalised whole sample fractions to allow direct comparison with ANZECC (2000) Guidelines.
- Macroinvertebrate abundance and diversity (infauna and epifauna).
- Other potentially toxic contaminants: these are measured in certain estuaries where a risk has been identified.

For the Shag Estuary, two fine scale sampling sites (Figure 1), were selected in unvegetated, mid-low water habitat. The lower estuary Site A comprised a 30m x 15m area in the dominant substrate of the estuary, while the upper estuary Site B comprised a 20m x 10m area in the main estuary deposition zone. Each site was marked out and divided into 12 equal sized plots. Within each area, ten plots were selected, a random position defined within each, and sampling undertaken as described in the following sections: plots were selected, a random position defined within each, and sampling undertaken as described in the following sections:

Physical and chemical analyses

- At each site, average apparent Redox Potential Discontinuity (aRPD) depth was recorded within three representative plots, and in one plot, redox potential (RP mV) was directly measured with an oxidation-reduction potential (ORP) meter at 0, 1, 3, 6 and 10cm depths below the surface.
- At each site, three samples (two a composite from four plots and one a composite from two plots) of the top 20mm of sediment (each approx. 250gms) were collected adjacent to each core for chemical analysis. All samples were kept in a chilly bin in the field before dispatch to R.J. Hill Laboratories for chemical analysis (details of lab methods and detection limits in Appendix 1):
- Samples were tracked using standard Chain of Custody forms and results checked and transferred electronically to avoid transcription errors.
- Photographs were taken to record the general site appearance.
- Salinity of the overlying water was measured at low tide.

Infauna (animals within sediments) and epiflora/fauna (surface dwelling plants and animals)

From each of 10 plots, 1 randomly placed sediment core (130mm diameter (area = 0.0133m^2) tube) was taken.

- The core tube was manually driven 150mm into the sediments, removed with the core intact and inverted into a labelled 0.5mm nylon mesh bag. Once all replicates had been collected at a site, the bags were transported to a nearby source of seawater and fine sediments were washed from the core. The infauna remaining were carefully emptied into a plastic container with a waterproof label and preserved in 70% isopropyl alcohol - seawater solution.

3. Methods (continued)

Figure 1. Location of water quality (orange) and fine scale monitoring (yellow) sites in Shag Estuary (Photo: Google).

- The samples were sorted by experienced Wriggle staff before being sent to a commercial laboratory for counting and identification (Gary Stephenson, Coastal Marine Ecology Consultants, Appendix 1).
- Where present, macroalgae and seagrass vegetation (including roots), was collected within each of three representative 0.0625m^2 quadrats, squeezed (to remove free water), and weighed in the field. In addition, the % cover of each plant type was measured.
- Conspicuous epifauna visible on the sediment surface within the 15m x 30m sampling area were semi-quantitatively assessed based on the UK MarClim approach (MNCR 1990, Hiscock 1996, 1998). Epifauna species are identified and allocated a SACFOR abundance category based on percentage cover (Table A, Appendix 1), or by counting individual organisms >5mm in size within quadrats placed in representative areas (Table B, Appendix 1). Species size determines both the quadrat size and SACFOR density rating applied, while photographs are taken and archived for future reference. This method is ideally suited to characterise often patchy intertidal epifauna, and macroalgal and microalgal cover.

Water quality and subtidal sediment

Three representative sites were selected in deep main channel sections in the lower, mid and upper estuary where there was a potential for estuary water to become stratified (Sites X, Y and Z respectively, see Figure 1).

3. Methods (continued)

At each site at high tide, a YSI-Sonde (6000 series) hand held field meter was deployed from a kayak to directly measure and log depth, chlorophyll *a*, salinity, temperature, pH, and dissolved oxygen in upper and lower 0.5m of the water column. At the same locations water samples were also collected with a van dorn water sampler for laboratory nutrient analyses (total N, nitrate-N, ammonia-N, dissolved reactive P and total P concentrations).

In addition, at each site secchi disc clarity was measured and one benthic sediment sample was collected using either a remotely triggered van veen grab sampler or a custom built sediment sampling hoe with telescopic handle). Once at the surface the sediment aRPD depth was measured, and a subsample collected for subsequent chemical analysis for TOC, grain size, TN and TP.

- All samples were kept in a chilly bin in the field before dispatch to R.J. Hill Laboratories for chemical analysis (details of lab methods and detection limits in Appendix 1):
- Samples were tracked using standard Chain of Custody forms and results checked and transferred electronically to avoid transcription errors.

Collecting water samples

Sediment accumulation

To determine the future sedimentation rate, a simple method of measuring how much sediment builds up over a buried plate over time is used. Once a plate has been buried and levelled, probes are pushed into the sediment until they hit the plate and the penetration depth is measured. A number of measurements on each plate are averaged to account for irregular sediment surfaces, and a number of plates are buried to account for small scale variance. These are then measured over time (commonly annually) to assess sediment accrual.

Two sites, each with four plates (20cm square concrete paving stones) were established in December 2016 in Shag Estuary at fine scale Sites A and B (Figure 1), with Site B representing the main deposition zone and Site A the main estuary basin. Plates were buried deeply in the sediments where stable substrate was located and positioned 2m apart in a linear configuration along the baseline of each fine scale site. Steel reinforcing rod was also placed horizontally next to each buried plate to enable relocation with a metal detector.

The GPS positions of each plate were logged, and the depth from the undisturbed mud surface to the top of the sediment plate recorded (Appendix 2). In the future, these depths will be measured annually and, over the long term, will provide a measure of the rate of sedimentation in the estuary.

4. RESULTS AND DISCUSSION

A summary of the results of the 9 December 2016 fine scale sediment and water quality monitoring of the Shag Estuary is presented in Tables 3 and 4, with detailed results in Appendices 2 and 3. Also included are the summary results of the preliminary fine scale sediment monitoring undertaken in 2006 (Stewart (2007).

Table 3. Mean fine scale sediment physical, chemical, plant growth (n=3) and macrofauna (n=10) results, Shag Estuary, November 2006 and 9 December 2016.

Year Site	RPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg	TN	TP
	cm	ppt	%				mg/kg									
2016 A	3	31	0.17	19.1	77.4	3.5	0.015	8.7	3.3	5.8	4.6	27.0	11.0	0.0147	<500	470
2016 B	3	32	0.35	23.0	51.9	25.1	0.024	9.6	5.3	8.2	5.8	36.0	16.4	0.0317	567	620
2006 D/S	3	NA	NA	29.4	51.9	18.7	0.04	10.2	5.0	6.7	5.6	33.6	9.2	NA	900	544
2006 U/S	1	NA	NA	18.3	76.1	5.5	0.02	10.5	3.9	7.1	4.7	30.2	11.0	NA	500	503

Year Site	Seagrass Biomass and Cover	Macroalgal Biomass and Cover	Macrofauna Abundance	Macrofauna Richness
	g.m^{-2} wet weight (%)	g.m^{-2} wet weight (%)	Individuals/m^2	Species/core
2016 A	0 (0%)	10 (<5%)	12668	6.0
2016 B	0 (0%)	10 (<5%)	2329	4.0
2006 D/S	0 (0%)	0 (0%)	2675	7.3
2006 U/S	0 (0%)	0 (0%)	4875	7.3

NA = Not Assessed

Table 4. Summary of fine scale water quality results (upper water column, bottom water column and bottom sediment, Shag Estuary, December 2016.

Parameter	Units	Shag Lower Site X (surface)	Shag Lower Site X (bottom)	Shag Mid Site Y (surface)	Shag Mid Site Y (bottom)	Shag Upstream Site Z (surface)	Shag Upstream Site Z (bottom)
Depth	m	0.1	0.63	0.1	0.75	0.1	0.8
Temperature	degrees C	16.8	16.6	16.9	16.9	17.7	16.3
Salinity	ppt	31.5	31.6	23.2	32.2	1.17	10.9
Dissolved Oxygen	mg/l	7.01	7.52	10.83	9.32	9.9	14.4
pH		8.3	8.4	8.5	7.8	8.2	8.7
Chlorophyll *a*	mg/m^3	0.1	0.8	1.5	30.8	0.5	227
Total Nitrogen	g/m^3	<0.3	<0.3	<0.3	0.5	0.4	3.1
Total Ammoniacal-N	g/m^3	0.021	0.023	0.017	0.036	0.02	1.7
Nitrate-N	g/m^3	0.01	0.01	0.006	0.014	0.102	<0.002
Dissolved Reactive Phosphorus	g/m^3	0.01	0.012	0.006	0.015	0.01	0.119
Total Phosphorus	g/m^3	0.024	0.027	0.011	0.057	0.011	0.33

Site	aRPD (cm)	TOC (%)	Mud (%)	Sand (%)	Gravel (%)	TP (mg/kg)	TN (mg/kg)
Shag Bottom Sediment Site X	>3	<0.05	1.5	98.1	0.5	185	<500
Shag Bottom Sediment Site Y	1	0.43	18.6	46.8	34.6	520	600
Shag Bottom Sediment Site Z	3	0.22	1.8	14.6	83.6	420	<500

4. Results and Discussion (continued)

Analysis and discussion of the 2016 results are presented as two main steps; firstly, the intertidal benthic habitat condition and secondly, the water column condition. The assessment is undertaken with a focus on the key SIDE estuary issues of muddiness (or sedimentation), eutrophication, and toxicity.

4.1 Benthic Habitat Condition

4.1.1 Muddiness (or Sedimentation)

The primary environmental variables that are most likely to be driving the ecological response in relation to estuary muddiness are sediment mud content (often the primary controlling factor) and sedimentation rate. Sediment mud content data are presented and assessed below, however, preliminary sedimentation rate data will not be available until December 2017.

Sediment Mud Content

Sediment mud content (i.e. % grain size <63µm) provides a good indication of the muddiness of a particular site. Estuaries with undeveloped catchments are generally sand dominated (i.e. grain size 63µm to 2mm) with very little mud (e.g. ~1% mud at Freshwater Estuary, Stewart Island), unless naturally erosion-prone with few wetland filters (e.g. Whareama Estuary, Wairarapa). In contrast, estuaries draining developed catchments typically have high sediment mud contents (e.g. >25% mud) in the primary sediment settlement areas e.g. where salinity driven flocculation occurs, or in areas that experience low energy tidal currents and waves (i.e. upper estuary intertidal margins and deeper subtidal basins). Well flushed channels or intertidal flats exposed to regular wind-wave disturbance generally have sandy sediments with a relatively low mud content (e.g. 2-10% mud).

Results showed the Shag Estuary fine scale sites had moderate (16-26% mud) sediment mud contents (Table 3, Figure 2).

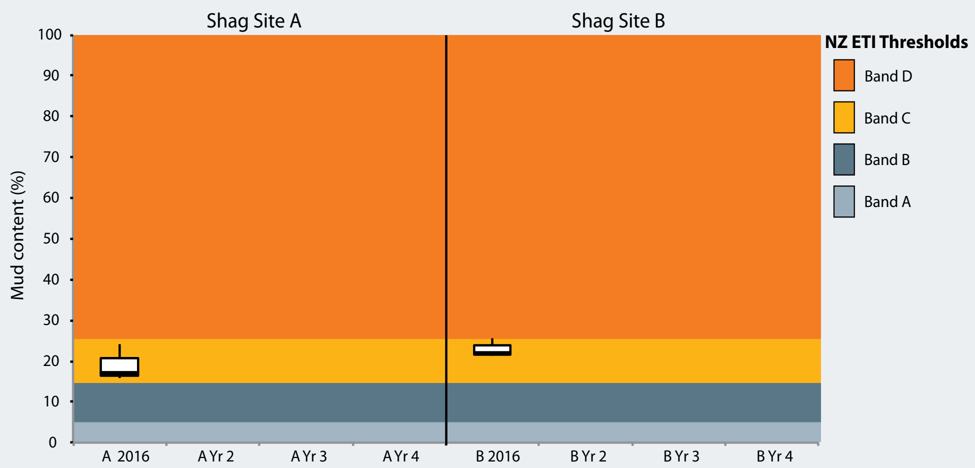

Figure 2. Mean mud content (median, interquartile range, total range, n=3), Shag Estuary, December 2016.

Site A (downstream) showed the sandiest sediments and had the largest variation, primarily because of the sites proximity to ocean-derived sands which intermittently mix with catchment derived muds. Site B (upstream) showed the highest gravel content (mean 25% gravel compared with 3.5% at Site A) reflecting the sites proximity to coarse sediments entering from the river (note that licensed gravel abstraction is undertaken from the estuary just below WQ Site Z (Figure 1). The overall moderate mud content fits the Band C rating, and indicates the following ecological conditions are likely (Robertson et al. 2016b):

- *Moderate stress on a number of aquatic organisms caused by the indicator exceeding preference levels for some species and a risk of sensitive macroinvertebrate species being lost, especially if nutrient loads elevated.*

4. Results and Discussion (continued)

Shag Estuary: Photographs taken December 2016

Upper estuary

Mid-estuary main channel

Lower estuary intertidal flats near main channel

Glasswort beds in the middle estuary

Muddy sands in the middle estuary

Soft mobile sands near the estuary mouth

4. Results and Discussion (continued)

4.1.2 Eutrophication

The primary variables indicating eutrophication impacts are sediment mud content, aRPD depth, sediment organic matter, nitrogen and phosphorus concentrations, and macroalgal and seagrass cover.

Macroalgae and Seagrass

The presence of opportunistic macroalgae on the sediment surface or entrained in the sediment, can provide organic matter and nutrients to the sediment which can lead to a degraded sediment ecosystem (Robertson et al. 2016b). In addition, seagrass (*Zostera muelleri*) cover and biomass on the sediment surface is also measured when present because seagrass can mitigate or offset the negative symptoms of eutrophication and muddiness. When seagrass losses occur it provides a clear indication of a shift towards a more degraded estuary state.

Results showed no seagrass and <5% cover of opportunistic macroalgae was present at Sites A and B (Figure 3). Such findings indicate low levels of eutrophication at the sites and that conditions are unsuitable for high value seagrass habitat.

Figure 3. Site A (left) and Site B (right) showing absence of opportunistic macroalgae and seagrass, Shag Estuary, December 2016.

Sediment Mud Content

This indicator has been discussed in the previous sediment section and is not repeated here. However, in relation to eutrophication, the moderate mud contents at both sites indicate sediment oxygenation is likely to be relatively poor.

Redox Potential Discontinuity (RPD)

The depth of the RPD boundary indicates the extent of oxygenation within sediments. Currently, the condition rating for redox potential is under development (Robertson et al. 2016b) pending the results of a PhD study in which aRPD and redox potential (RP) measured with an ORP electrode and meter, are being assessed for a gradient of eutrophication symptoms. Initial findings indicate that the recommended NZ estuary aRPD and redox potential thresholds are likely to reflect those put forward by Hargrave et al. (2008) (see Table 2 and Figure 3).

Figure 4 shows the aRPD depths from the surface, and redox potentials (5 depths at each site, mean of triplicate measures plotted) for the two Shag Estuary sampling sites for December 2016.

The results show that the aRPD depth was 3cm at both Sites A and B. The redox potential for the sites (Figure 4) indicate that in the upper ~3cm sediments are sufficiently well oxygenated to support a range of sensitive taxa but below this depth poor oxygenation conditions are present (i.e. low redox <-150mV, Band D). The low redox levels at depths greater than 3cm indicate sediment oxygenation at such depths is likely to support predominantly tolerant opportunistic species (see Section 4.1.4).

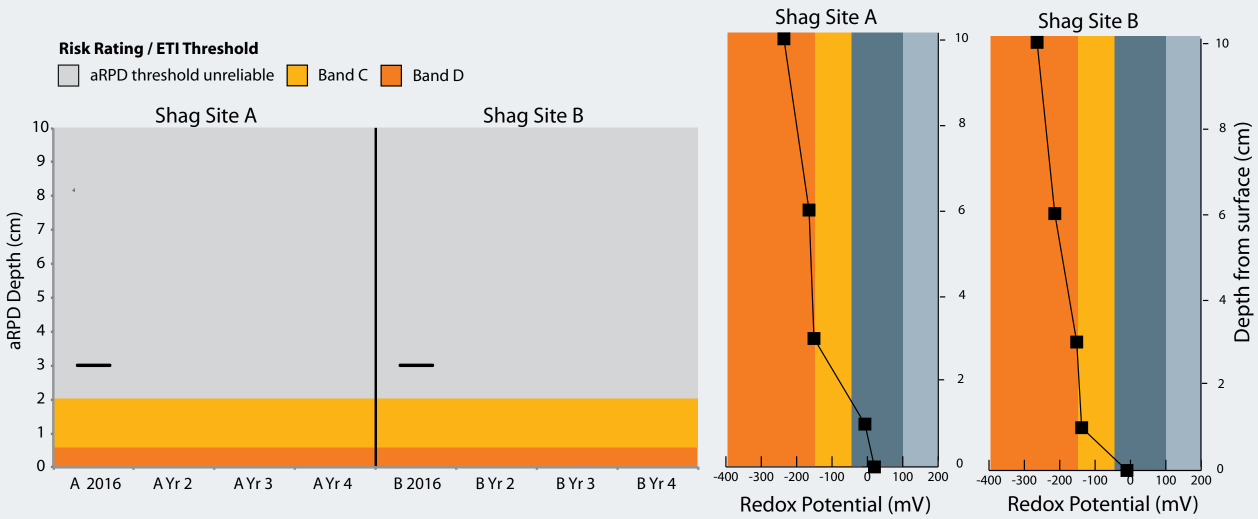

Figure 4. Mean apparent Redox Potential Discontinuity (aRPD) depth, (median, interquartile range, total range, n=3), and Redox Potential (RPmV) at 5 depths, Shag Estuary Sites A and B, December 2016.

Total Organic Carbon and Nutrients

The concentrations of sediment organic matter (TOC) and nutrients (TN and TP) provide valuable trophic state information. In particular, if concentrations are elevated and eutrophication symptoms are present [i.e. shallow aRPD, excessive algal growth, high NZ AMBI biotic coefficient (see the following macroinvertebrate condition section)], then elevated TN, TP and TOC concentrations provide strong supporting information to indicate that loadings are exceeding the assimilative capacity of the estuary.

Results for the two sites showed TOC (<0.5%) and TN (<600mg/kg) were in the "very low" or "low" risk indicator ratings, while TP (rating not yet developed) was relatively low at 470-620mg/kg (Figures 5, 6 and 7).

Synoptic fine scale monitoring results collected from two sites in November 2006 (Stewart 2007) are presented alongside the current results in Table 3 and show 2006 results were similar to those from nearby Sites A and B in 2016, indicating those parts of the estuary are unlikely to have significantly changed over in the past decade. However, the 2006 synoptic survey has not been comprehensively assessed in the current report as it did not meet the requirements of a full baseline survey (e.g. involved one-off sampling outside of the recommended December-March summer period, used limited replication (a single composite chemistry sample and 3 macroinvertebrate replicates instead of the recommended 10), did not assess the high susceptibility upper estuary arm, and did not monitor for water column eutrophication).

4. Results and Discussion (continued)

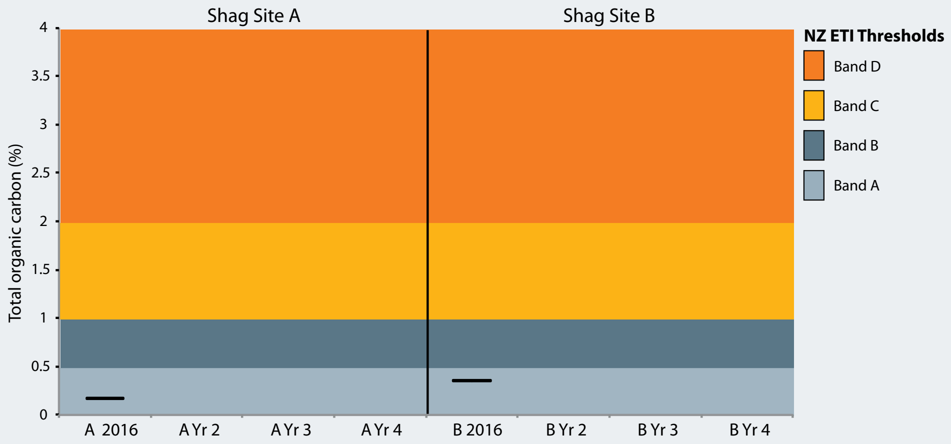

Figure 5. Mean total organic carbon (median, interquartile range, total range, n=3), December 2016.

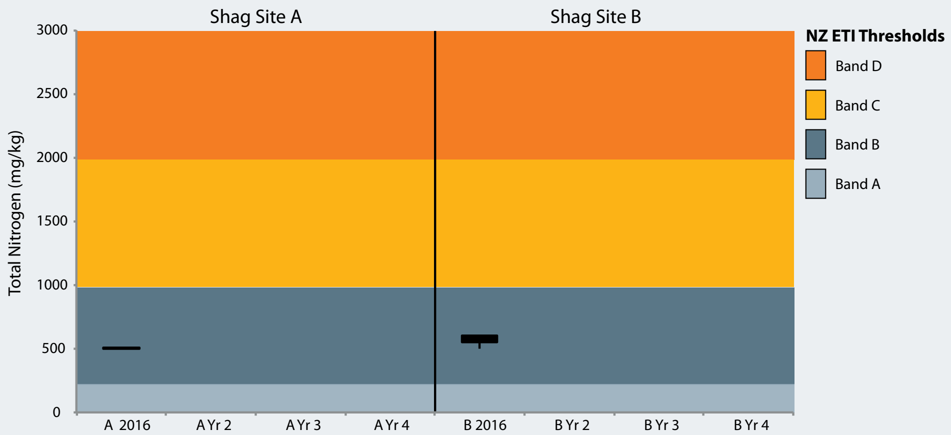

Figure 6. Mean total nitrogen (median, interquartile range, total range, n=3), December 2016.

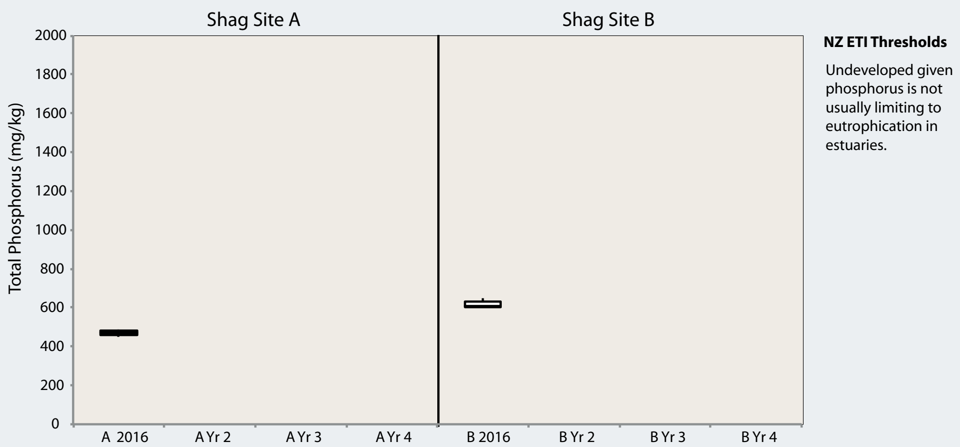

Figure 7. Mean total phosphorus (median, interquartile range, total range, n=3), December 2016.

4.1.3 Toxicity

The influence of non-eutrophication related toxicity is primarily indicated by concentrations of heavy metals, with pesticides, PAHs, and SVOCs generally only assessed where inputs are likely, or metal concentrations are found to be elevated.

Results for heavy metals Cd, Cr, Cu, Hg, Pb, Ni, Zn and arsenic, used as indicators of potential toxicants, were rated "moderate" for arsenic and "very low" to "low" for all other parameters. All non-normalised values were below the ANZECC (2000) ISQG-Low trigger values (Table 5) and therefore indicate the toxicant indicators monitored posed no threat to aquatic life.

Table 5. Indicator toxicant results for Shag Estuary (Sites A and B), December 2016.

Year/Site/Rep	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg
	mg/kg							
2016 A 1-4 [b]	0.013	8.5	3.3	5.6	4.5	27	10.3	0.011
2016 A-4-8 [b]	0.015	8.7	3.4	5.9	4.7	27	11.5	0.016
2016 A-9-10 [b]	0.018	8.9	3.3	5.8	4.7	27	11.1	0.017
2016 B-1-4 [b]	0.025	9.8	5.3	8.2	5.9	37	15.6	0.033
2016 B-4-8 [b]	0.026	9.4	5.4	8.3	5.9	36	16.7	0.032
2016 B-9-10 [b]	0.021	9.5	5.2	8.0	5.7	35	16.9	0.03
Condition Thresholds (ANZECC 2000 criteria, Very Low, <0.2 x ISQG Low; Low, 0.2 - 0.5 x ISQG Low; Moderate, 0.5 x to ISQG Low; High, >ISQG Low)								
[a] Band A Very Low Risk	<0.3	<16	<13	<4.2	<10	<40	<4	<0.03
[a] Band B Low Risk	0.3 - 0.75	16 - 40	13 - 32.5	4.2 - 10.5	10 - 25	40 - 100	4 - 10	0.03 - 0.075
[a] Band C Moderate Risk	0.75 - 1.5	40 - 80	32.5 - 65	10.5 - 21	25 - 50	100 - 200	10 - 20	0.075 - 0.15
[a] Band D High Risk	>1.5	>80	>65	>21	>50	>200	>20	>0.15
[a] ISQG-Low	1.5	80	65	21	50	200	20	0.15
[a] ISQG-High	10	370	270	52	220	410	70	1

[a] ANZECC 2000, * composite samples

4.1.4 Benthic Macroinvertebrate Community

Benthic macroinvertebrate communities are considered good indicators of ecosystem health in shallow estuaries because of their strong primary linkage to sediments and secondary linkage to the water column (Dauer et al. 2000, Thrush et al. 2003, Warwick and Pearson 1987, Robertson et al. 2016). Because they integrate recent disturbance history in the sediment, macroinvertebrate communities are therefore very effective in showing the combined effects of pollutants or stressors.

The response of macroinvertebrates to stressors in the Shag Estuary will be analysed in detail once sufficient baseline monitoring data is available. This analysis will include four steps:

1. Ordination plots to enable an initial visual overview (in 2-dimensions) of the spatial and temporal structure of the macroinvertebrate community among each fine scale site over time.
2. The BIO-ENV program in the PRIMER (v.6) package will be used to evaluate and compare the relative importance of different environmental factors and their influence on the identified macrobenthic communities.
3. Assessment of species richness, abundance, diversity and major infauna groups.
4. Assessment of the response of the macroinvertebrate community to increasing mud and organic matter among fine scale sites over time, based on identified tolerance thresholds for NZ taxa (NZ AMBI, Robertson et al. 2015, Robertson et al. 2016).

At this stage, with only one year of monitoring data, this section of the report will present and interpret data in relation to steps 3 and 4 only.

Species Richness, Abundance, Diversity and Infauna Groups

In this step, simple univariate whole community indices, i.e. species richness, abundance and diversity are presented for each site (Figure 8) and in the future when more data are available, will be used to help explain any differences between years indicated by other analyses.

At the mid estuary Site B, the data showed relatively low species richness (2-6 per core), abundance (18-58 per core) and Shannon diversity (0.49-0.98 per core), slightly lower than the fine scale sites in Waimea Inlet [i.e. species richness (6-13 per core), abundance (8-83 per core) and Shannon diversity (1.4-2.4 per core) - Robertson and Stevens 2014)], but a lot lower than Porirua Harbour [i.e. species richness (10-25 per core), abundance (50-220 per core) and Shannon diversity (1.1-1.6 per core) - Robertson and Stevens 2015)]. On the other hand, the more marine influenced and slightly sandier lower estuary Site A had a much greater abundance (71-254 per core) than Site B and a slightly higher species richness (4-8 per core).

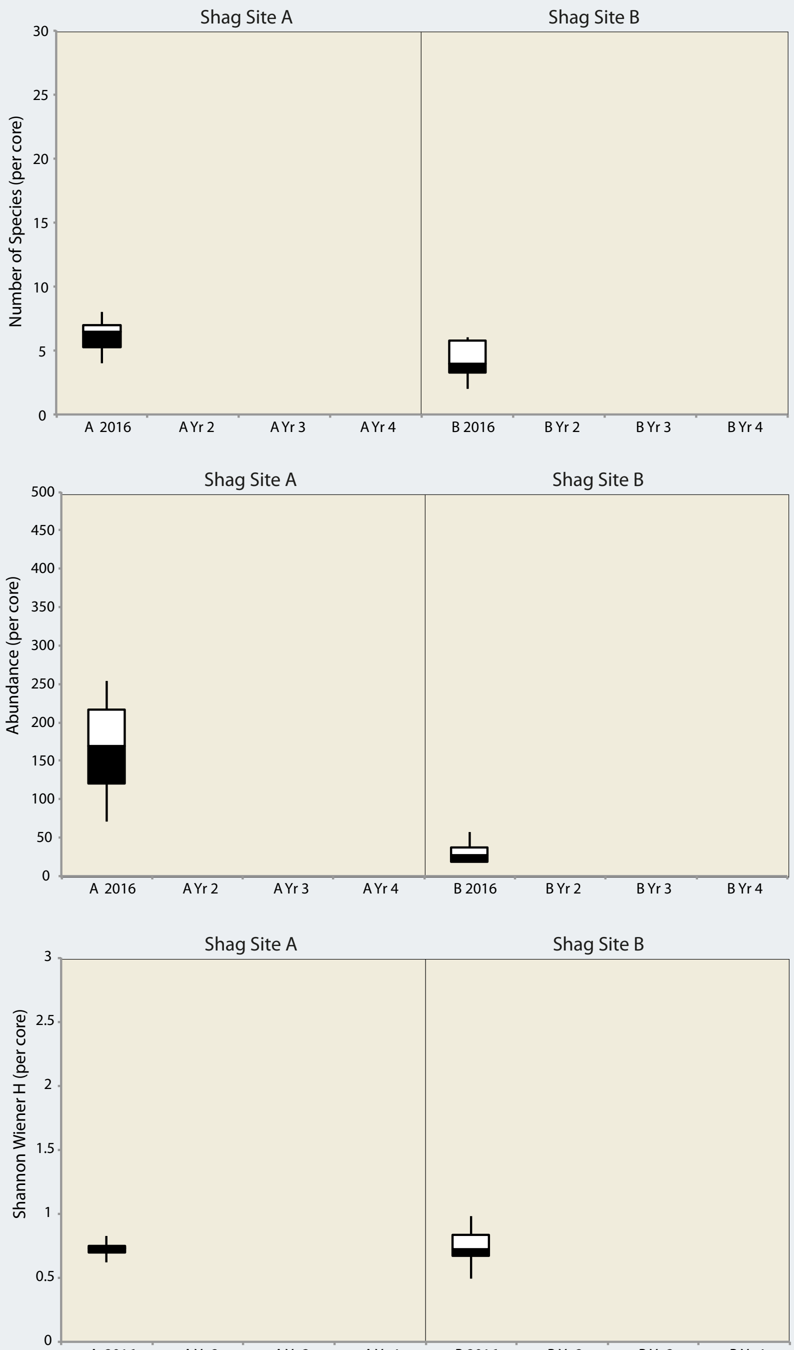

Figure 8. Mean number of species, abundance per core, and Shannon Diversity index (±SE, n=10), Shag Estuary, December 2016.

4. Results and Discussion (continued)

Figure 9 shows that, although the macroinvertebrate community was dominated by crustacea and polychaetes at both sites, there were obvious differences in abundance with Site A having the greatest numbers of each group. The plot also shows that bivalves were only present at Site A. These differences are discussed in more detail in the following sections.

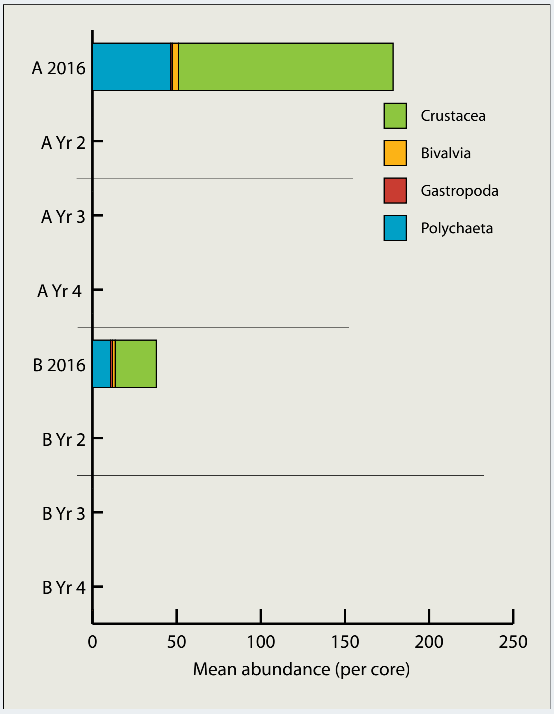

Figure 9. Mean abundance of major infauna groups (n=10), Shag Estuary, December 2016.

Macroinvertebrate Community in Relation to Mud and Organic Enrichment

1. Mud and Organic Enrichment Index (NZ AMBI)

This step is undertaken by using the NZ AMBI (Robertson et al. 2016), a benthic macroinvertebrate index based on the international AMBI approach (Borja et al. 2000) which includes several modifications to strengthen its response to anthropogenic stressors, particularly mud and organic enrichment as follows:

- integration of previously established, quantitative ecological group classifications (Robertson et al. 2015),
- addition of a meaningful macrofaunal component (taxa richness), and
- derivation of classification-based and breakpoint-based thresholds that delineated benthic condition along primary estuarine stressor gradients (in this case, sediment mud and total organic carbon contents). The latter was used to evaluate the applicability of existing AMBI condition bands, which were shown to accurately reflect benthic condition for the >100 intertidal NZ estuarine sites surveyed: 2% to ~30% mud reflected a “normal” to “impoverished” macrofauna community, or “high” to “good” status; ~30% mud to 95% mud and TOC ~1.2% to 3% reflected an “unbalanced” to “transitional to pollution” macrofauna community, or “good” to “moderate” status; and >3% to 4% TOC reflected a “transitional to pollution” to “polluted” macrofauna community, or “moderate” to “poor” status.

In addition, the AMBI was successfully validated (R^2 values >0.5 for mud, and >0.4 for total organic carbon) for use in shallow, intertidal dominated estuaries New Zealand-wide.

For the two fine scale sites in the Shag Estuary, the NZ Hybrid AMBI biotic coefficients were relatively similar, with medians of 4.12 at Site A and 4.30 at Site B (Figure 10). The coefficients indicate that both Sites A and B were in the "moderate-poor" ecological condition categories (i.e. an unbalanced to impoverished type community, with limited sub-surface organisms, indicative of moderate-high high mud concentrations, possibly accompanied by organic enrichment).

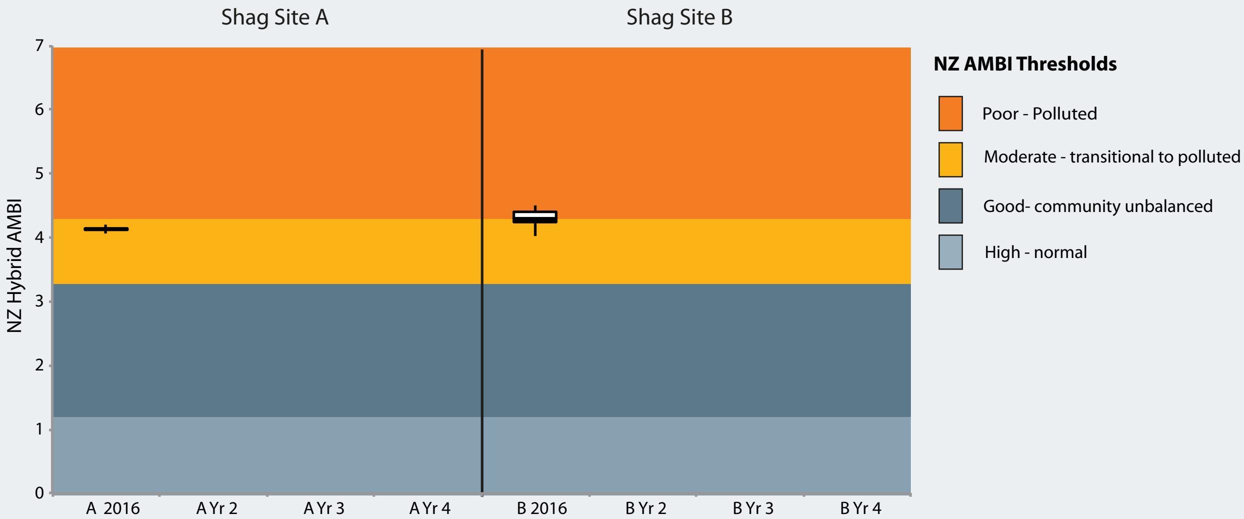

Figure 10. Benthic invertebrate NZ AMBI mud/organic enrichment tolerance rating (median, interquartile range, total range, n=10), Shag Estuary, December 2016.

2. Individual Species

To further explore the macroinvertebrate community in relation to taxa sensitivities to mud and organic enrichment, a comparison was made of the mean abundances of individual taxa within the 5 major mud/enrichment tolerance groupings (i.e. *1 = highly sensitive to (intolerant of) mud and organic enrichment; 2 = sensitive to mud and organic enrichment; 3 = widely tolerant of mud and organic enrichment; 4 = prefers muddy, organic enriched sediments; 5 = very strong preference for muddy, organic enriched sediments*) (Figure 11).

The key findings were as follows:

- Highly sensitive Group 1 organisms were completely absent from Site B and had only one representative at Site A, the long, slender, burrowing, deposit-feeding orbiniid polychaete *Scoloplos cylindrifer.*
- Group 2 organisms were present in low numbers at each site, including the suspension-feeding cockle, *Austrovenus stutchburyi.*
- Group 3 and 4 organisms dominated at both Sites A and B, particularly the slender burrowing polychaete *Paradoneis* sp., the surface deposit feeding spionid polychaete *Scolecolepides benhami* and, to a much greater extent, the tube-dwelling crustacean amphipod *Paracorophium excavatum*, which is the dominant corophioid amphipod in the South Island. *Paracorophium* is well-known as a major primary coloniser (and hence indicator) of disturbed estuarine intertidal flats (Ford et al. 1999). Examples of common disturbances are macroalgal mats settling on the tidal flats as a result of coastal eutrophication, and mud deposition after mobilisation of fine sediments from exposed soil surfaces in the catchment. In these situations, *Paracorophium* can become very abundant and, through its burrowing activities, increases oxygen exchange which in turn mitigates the effect of the disturbance.
- Organisms with a very strong preference for muddiness were relatively rare at both sites.

Figure 11. Mud and organic enrichment sensitivity of macroinvertebrates, Shag Estuary Sites A and B, December 2016 (see Appendix 3 for sensitivity details).

4.2 Water Column Condition

Background

In NZ SIDEs the rapid flushing time (<3 days for these estuaries) means water column phytoplankton cannot reach high concentrations before they are flushed to the sea. As a consequence, water column eutrophication is minimal, except for some estuaries where parts of the upper estuary water column can be more poorly flushed. This occurs in low flow-baseflow periods when inflowing freshwater flows over more saline tidal water and results in a dense isolated layer of saline bottom water that neither freshwater or tidal inflow currents are strong enough to flush out. Such isolated (or stratified) bottom water (often situated in the 1-2m depth range) is susceptible to phytoplankton blooms, low dissolved oxygen, elevated nutrient concentrations and accumulation of fine sediment.

In estuaries where stratification occurs, the preferred target for eutrophication management is nitrogen which has been identified as the element most limiting to algal production in most estuaries in the temperate zone (Howarth and Marino 2006). Since nitrogen is continually cycling between all of the major nitrogen forms, an assessment of total nitrogen (TN) is needed in order to gauge the level of nitrogen within an embayment and therefore its potential nutrient related health. Reliance on a nitrogen fraction, e.g. inorganic nitrogen, results in inaccurate assessments, since even in a large algal bloom inorganic concentrations may be low due to the uptake by the plants (Howes et al. 2003). Based on the following literature, a TN threshold concentration of approximately 400ugTN.l^{-1} (0.4mgNl^{-1}) for the appearance of eutrophic conditions in poorly flushed sections of SIDE estuaries can be identified (see inset).

Literature Supporting TN Threshold

- In Horsen's Estuary, Denmark, research indicates a mean growing season threshold value of 0.398mgTN l^{-1} to meet good ecological status (Hinsby et al. 2012). This research also identified a threshold for inorganic nutrients as 0.021mgDIN l^{-1} and 0.007mgDIP l^{-1}.
- Similarly, ECan Avon-Heathcote Estuary data from 2010-2014 suggests the appearance of eutrophic conditions may be unlikely below a TN concentration around 0.4mgTN/l (John Zeldis pers. comm. 2016).
- In the US, EPA Region 1 has considered total N threshold concentrations for estuaries and coastal waters of 0.45mgTN l^{-1} as protective of DO standards and 0.34mgTN l^{-1} as protective for eelgrass (Latimer and Rego 2010, State of New Hampshire 2009, Benson et al. 2009).
- As concentrations at inner Massachusetts estuaries rose to levels above 0.40gTN l^{-1}, with the entry of a wastewater nitrogen plume, eelgrass beds began declining and localized macro-algal accumulations were reported (Howes et al. 2003).

Results

The water quality results for the surface and bottom waters at three sites in the Shag Estuary (lower, mid and upper estuary sites, Sites X, Y and Z respectively) are presented in Table 4 (see Figure 1 for site locations). The main findings were as follows:

Stratification

There was minimal difference between surface and bottom water temperature (Figure 12), but salinity (Figure 12), chlorophyll *a* and dissolved oxygen (Figure 15) indicated stratification was occurring at the upper and mid estuary sites when sampled on 9 December 2016. The presence of water column stratification, and the consequent likelihood of poorly flushed bottom water, means there is a high potential for intermittent eutrophication of the estuary water column as discussed on the following pages.

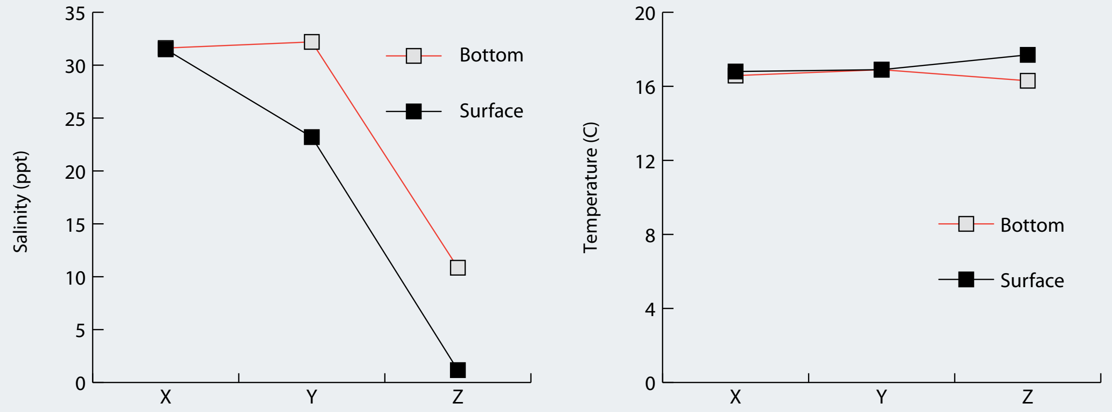

Figure 12. Salinity and temperature in surface and bottom water, Shag Estuary, 9 December 2016.

Susceptibility To Eutrophication Based on TN Concentrations

Total nitrogen (TN) concentrations in the surface waters at all sites were less than the eutrophication threshold level of 0.4mgNl^{-1}, with the upper estuary Site Z having the highest concentrations. However, the denser saline bottom water at the middle estuary Site Y and the upper estuary Site Z both exceeded the threshold level. Although some previous water quality data exists for the estuary, it was restricted to surface waters at one site only and was measured prior to 2010 (ORC SOE Report 2010) so was not considered for inclusion.

The results indicate a high likelihood of eutrophication symptoms (e.g. high chlorophyll *a* concentrations) being present in the bottom water at the middle and upper sites. However, in this case, where data for only one discrete event were collected, the results can only be used as an early indicator of likely growing season susceptibility. To assess the susceptibility to eutrophication over the whole growing season (November-April), monthly TN concentrations should be used.

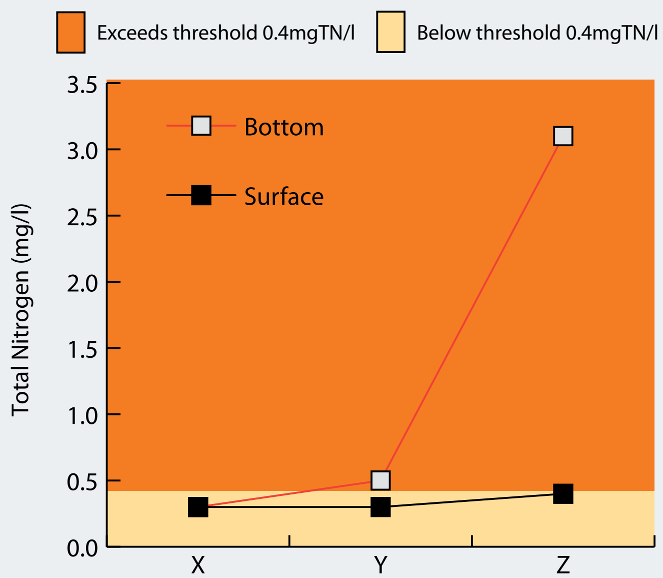

Figure 13. Total nitrogen concentration in surface and bottom water, Shag Estuary, 9 December 2016.

Other measurements of plant nutrients showed relatively low levels in surface waters, but higher concentrations of ammoniacal N, TP, and DRP in stratified bottom waters at the mid and upper estuary sites (Table 4, Figure 14).

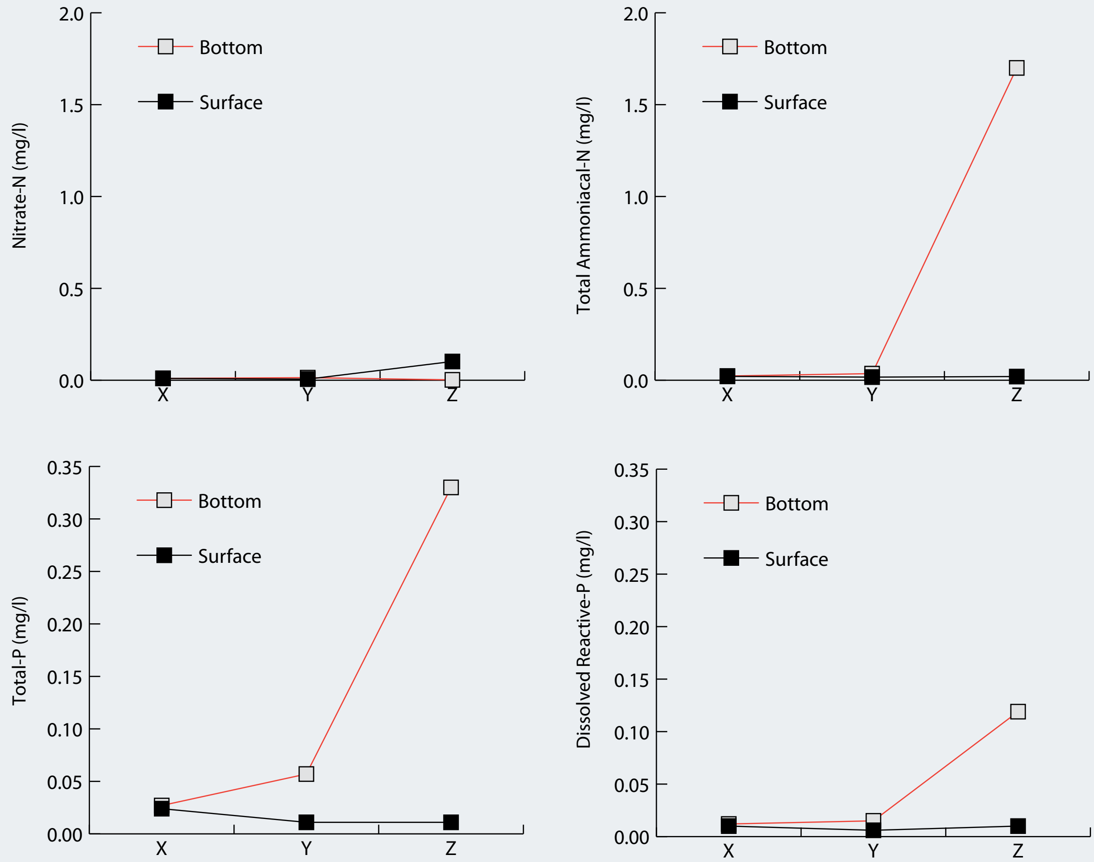

Figure 14. Nitrate N, Ammoniacal N, TP, and DRP concentrations in surface and bottom water, Shag Estuary, 9 December 2016.

Eutrophic Status Based on Chlorophyll a and Dissolved Oxygen

The NZ ETI threshold for chlorophyll *a* (the primary indicator of water column eutrophication) is expressed as the 90th percentile of monthly measures collected during the growing season, and for dissolved oxygen (the main eutrophication supporting indicator), a 7 day mean. Consequently the one-off measures collected on 9 December 2016 can only be used as an indication of current condition.

In the surface waters at each site, chlorophyll *a* concentrations were all very low (<1ugl^{-1}, Figure 15). However, in denser saline bottom water at Site Y (mid estuary) and the Site Z (upper estuary) exceeded the NZ ETI threshold level of 16ugl^{-1} (Robertson et al. 2016b). In particular, Site Z bottom water had a very high concentration (i.e. 227ugl^{-1} chlorophyll *a*).

The same sites had supersaturated dissolved oxygen concentrations in bottom water during daylight (157% and 128% at sites Z and Y respectively), indicating a potential for depression to low levels during the night. Both these indicators highlight potentially significant eutrophication issues in the estuary.

4. Results and Discussion (continued)

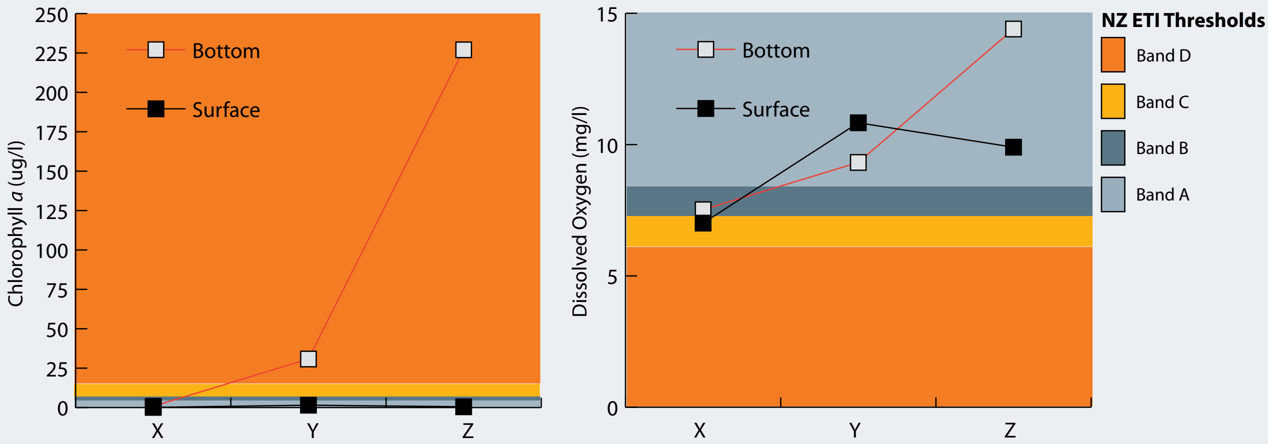

Figure 15. Chlorophyll *a* and dissolved oxygen concentrations in surface and bottom water, Shag Estuary, 9 December 2016.

Water Quality Overview

The data show, in particular, high concentrations of ammonia and phosphorus (both TP and DRP) in the bottom water at Site Z, with ammoniacal N accounting for 55% of the total N concentration. Also of note, was the complete absence of nitrate-N at site. Taken in combination, the results indicate nutrient (DRP and ammonia) release from the sediment under anaerobic conditions, a key indicator of the presence of eutrophic conditions. Although, the sediment results at each of the sites showed little evidence of elevated sediment nutrients or strong anoxia (Table 4), it is possible that such conditions existed upstream or between the sites and was causing the degraded water quality at the sites through dilution and diffusion within the estuary.

5. SUMMARY AND CONCLUSIONS

Fine scale results of estuary condition for two long term intertidal monitoring sites within Shag Estuary in December 2016 showed the following findings in relation to the key estuary issues of eutrophication, muddiness and toxicity:

BENTHIC HABITAT

Muddiness

The intertidal sites, chosen to represent the main benthic habitats in the estuary, showed a moderate mud content (16-26% mud), with slightly muddier sediments in the estuary's main deposition zone (Site B - mean 23% mud) and sandier sediments in the lower estuary (Site A - mean 19% mud). The mud contents for Sites A and B indicate a *moderate potential for stress on a number of aquatic organisms caused by the indicator exceeding preference levels for some species and a risk of sensitive macroinvertebrate species being lost, especially if nutrient loads elevated* (Robertson et al. 2016b).

Eutrophication

The macroalgal results show that in December 2016 there was no seagrass cover and less than 5% cover of opportunistic macroalgae at both Sites A and B. In addition, while underlying sediments at both sites had low organic carbon and nutrient contents both showed poor oxygenation conditions (i.e. low redox <-150mV, Band D) beginning below ~3cm depth.

The combination of moderate mud content and poor oxygenation indicates that the macroinvertebrate community would likely to be dominated by mud tolerant species. Such a biological response was reflected in the NZ estuary macroinvertebrate community index (the NZ Hybrid AMBI) results, median 4.1 at Site A and 4.3 at Site B. These coefficients indicate a moderate-poor ecological condition category (i.e. an unbalanced to impoverished type community indicative of elevated mud concentrations, possibly accompanied by organic enrichment).

5. Summary and Conclusions (continued)

Toxicity

Indicators of sediment toxicants [heavy metals (Cd, Cr, Cu, Pb, Hg, Ni, Zn and As)] were at concentrations that were not expected to pose toxicity threats to aquatic life.

WATER COLUMN HABITAT

Eutrophication

Taken as a whole, the December 2016 data showed that the bottom water in the middle and upper estuary was eutrophic, as indicated by very high chlorophyll *a* and ammonia concentrations and the presence of TN exceeding the eutrophication threshold concentration. The data also showed that the remainder of the estuary had a low susceptibility to water column eutrophication and no indication of phytoplankton blooms.

However, given only one comprehensive sampling event, questions remain around the likely duration, magnitude and frequency of such eutrophication symptoms.

Based on expert opinion, they likely manifest as cycles of bottom water stratification and accompanying eutrophication, that gradually increase towards the end of the cycle, with the cycles being broken by intermittent high flow events that disrupt the stratification and flush phytoplankton and nutrients into the main body of the estuary and out to sea. The magnitude of the blooms will likely depend on the duration between flood events, with nuisance conditions increasing as time between floods increases.

Although upper estuary bottom water stratification is a natural event in many shallow NZ estuaries, it can be exacerbated by reductions in natural river inflows (e.g. from upstream water abstraction and damming). Once established, the extent of eutrophication in the bottom layer is likely to be primarily driven by catchment nutrients, particularly nitrogen. Preliminary indications suggest that river total nitrogen inputs would need to be much less than 0.4mgNl^{-1} in order to minimise eutrophication symptoms in this sensitive zone of an estuary.

In terms of risk to estuarine ecology from this cyclical degradation of the upper-mid estuary bottom water layer, the likely main threats would be to benthic macroinvertebrates and fish through loss of important habitat.

Overview

In overview, the benthic habitat results indicate the estuary expresses symptoms of moderate muddiness and low levels of eutrophication (moderate mud content and low macroalgal cover). However, the combination of moderate muddiness and poor sediment oxygenation have resulted in an unbalanced to impoverished type macroinvertebrate community.

The water column results indicate upper estuary stratification at the time of sampling, expressed by very high chlorophyll *a* and ammonia concentrations, and the presence of TN exceeding the eutrophication threshold concentration.

The "Overview Report" which accompanies the current fine and broad scale reports identifies appropriate nutrient load versus estuary eutrophication response thresholds that can be used to manage these issues, as well as providing more details on the issues.

6. MONITORING

Monitoring

Shag Estuary has been identified by ORC as a priority for monitoring because it is a moderate sized estuary with high ecological and human use values that is situated in a developed catchment, and therefore vulnerable to excessive sedimentation and eutrophication. As a consequence, it is a key part of ORC's coastal monitoring programme being undertaken throughout the Otago region. Broad scale habitat mapping and fine scale sampling has now been undertaken for 1 baseline year (December 2016).

6. MONITORING

In order to assess ongoing long-term trends in the condition of such estuaries, it is common practice amongst NZ Regional Councils to establish a strong baseline against which future trends can be compared. This typically comprises comprehensive broad scale habitat mapping on a 5-10 yearly cycle, targeted annual monitoring where specific issues are identified (e.g. opportunistic nuisance macroalgal growth), and fine scale monitoring comprising 3-4 consecutive years of baseline monitoring, followed by 5 yearly impact monitoring.

The present report addresses the fine scale component of the long term programme. The recommendation for ongoing monitoring to meet this requirement for the Shag Estuary is as follows:

Fine Scale Monitoring

To complete the fine scale baseline in Shag Estuary it is recommended that the remaining 3 consecutive years of annual summer (i.e. December-February) fine scale monitoring of intertidal sites (including sedimentation rate measures), be undertaken in 2017, 2018 and 2019 (preferably during a summer, low flow period).

To fully characterise the potential for upper estuary stratification and eutrophication, it is recommended that water column monitoring of the upper to mid estuary be undertaken during a summer, prolonged low flow period in 2018. It is envisaged that this should include sampling of surface and bottom water at 5-6 sites in the main channel of the estuary.

To characterise the potential for excessive sedimentation, it is recommended that sedimentation rates be assessed annually, using appropriately placed sediment plates, and the areal extent of muddy sediments be assessed at 5-10 yearly intervals (the latter assessed in broad scale monitoring).

Broad Scale Habitat Mapping

To characterise any issues of change in habitat (e.g. saltmarsh or seagrass area, soft mud extent, opportunistic macroalgae), it is recommended that broad scale habitat mapping be undertaken at 10 yearly intervals (next scheduled for 2026) unless obvious changes are observed in the interim.

7. ACKNOWLEDGEMENTS

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APPENDIX 1. DETAILS ON ANALYTICAL METHODS

Indicator	Laboratory	Method	Detection Limit
Infauna Sorting and ID	CMES	Coastal Marine Ecology Consultants (Gary Stephenson) *	N/A
Grain Size	R.J Hill	Wet sieving, gravimetric (calculation by difference).	0.1 g/100g dry wgt
Total Organic Carbon	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	0.05g/100g dry wgt
Total recoverable cadmium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.01 mg/kg dry wgt
Total recoverable chromium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable copper	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable nickel	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable lead	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.04 mg/kg dry wgt
Total recoverable zinc	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.4 mg/kg dry wgt
Total recoverable mercury	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	<0.27 mg/kg dry wgt
Total recoverable arsenic	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	<10 mg/kg dry wgt
Total recoverable phosphorus	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	40 mg/kg dry wgt
Total nitrogen	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	500 mg/kg dry wgt
Dry Matter (Env)	R.J. Hill	Dried at 103°C (removes 3-5% more water than air dry)	

* Coastal Marine Ecology Consultants (established in 1990) specialises in coastal soft-shore and inner continental shelf soft-bottom benthic ecology. Principal, Gary Stephenson (BSc Zoology) has worked as a marine biologist for more than 25 years, including 13 years with the former New Zealand Oceanographic Institute, DSIR. Coastal Marine Ecology Consultants holds an extensive reference collection of macroinvertebrates from estuaries and soft-shores throughout New Zealand. New material is compared with these to maintain consistency in identifications, and where necessary specimens are referred to taxonomists in organisations such as NIWA and Te Papa Tongarewa Museum of New Zealand for identification or cross-checking.

Water Quality Indicator	Laboratory	Method	Detection Limit
Filtration, Unpreserved	R.J Hill	Sample filtration through 0.45µm membrane filter.	-
Total Kjeldahl Digestion	R.J Hill	Sulphuric acid digestion with copper sulphate catalyst.	-
Total Phosphorus Digestion	R.J Hill	Acid persulphate digestion.	-
Total Nitrogen	R.J Hill	Calculation: TKN + Nitrate-N + Nitrite-N. Please note: Default Detection Limit of 0.05 g/m3 is only attainable when the TKN has been determined using a trace method utilising duplicate analyses. In cases where the Detection Limit for TKN is 0.10 g/m3, the Default Detection Limit for Total Nitrogen will be 0.11 g/m3.	0.05 g/m^3
Total Ammoniacal-N	R.J Hill	Saline, filtered sample. Phenol/hypochlorite colorimetry. Discrete Analyser. (NH4-N = NH4+-N + NH3-N). APHA 4500- NH3 F (modified from manual analysis) 22nd ed. 2012.	0.010 g/m^3
Nitrite-N	R.J Hill	Saline sample. Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO3- I 22nd ed. 2012 (modified).	0.002 g/m^3
Nitrate-N	R.J Hill	Calculation: (Nitrate-N + Nitrite-N) - NO2N. In-House.	0.0010 g/m^3
Nitrate-N + Nitrite-N	R.J Hill	Saline sample. Total oxidised nitrogen. Automated cadmium reduction, Flow injection analyser. APHA 4500-NO3- I 22nd ed. 2012 (modified).	0.002 g/m^3
Total Kjeldahl Nitrogen (TKN)	R.J Hill	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-Norg D. (modified) 4500 NH3 F (modified) 22nd ed. 2012.	0.10 g/m^3
Dissolved Reactive Phosphorus	R.J Hill	Filtered sample. Molybdenum blue colorimetry. Discrete Analyser. APHA 4500-P E (modified from manual analysis) 22nd ed. 2012.	0.004 g/m^3
Total Phosphorus	R.J Hill	Total phosphorus digestion, ascorbic acid colorimetry. Discrete Analyser. APHA 4500-P B & E (modified from manual analysis) 22nd ed. 2012. Also modified to include the use of a reductant to eliminate interference from arsenic present in the sample. NWASCA, Water & soil Miscellaneous Publication No. 38, 1982.	0.004 g/m^3

Appendix 1. Details on Analytical Methods (continued)

Epifauna (surface-dwelling animals).
SACFOR Percentage Cover and Density Scales (after Marine Nature Conservation Review - MNCR).

A. PERCENTAGE COVER	Growth Form	
	i. Crust/Meadow	ii. Massive/Turf
>80	S	-
40-79	A	S
20-39	C	A
10-19	F	C
5-9	O	F
1-4	R	O
<1	-	R

SACFOR Category
S = Super Abundant
A = Abundant
C = Common
F = Frequent
O = Occasional
R = Rare

- Whenever percentage cover can be estimated for an attached species, it should be used in preference to the density scale.
- The massive/turf percentage cover scale should be used for all species except those classified under crust/meadow.
- Where two or more layers exist, for instance foliose algae overgrowing crustose algae, total percentage cover can be over 100%.

B. DENSITY SCALES

SACFOR size class				Density				
i	ii	iii	iv	$0.25m^2$	$1.0m^2$	$10m^2$	$100m^2$	$1,000m^2$
<1cm	1-3cm	3-15cm	>15cm	(50x50cm)	(100x100cm)	(3.16x3.16m)	(10x10m)	(31.6x31.6m)
S	-	-	-	>2500	>10,000			
A	S	-	-	250-2500	1000-9999	>10,000		
C	A	S	-	25-249	100-999	1000-9999	>10,000	
F	C	A	S	3-24	10-99	100-999	1000-9999	>10,000
O	F	C	A	1-2	1-9	10-99	100-999	1000-9999
R	O	F	C			1-9	10-99	100-999
-	R	O	F				1-9	10-99
-	-	R	O					1-9
-	-	-	R					<1

APPENDIX 2. 2016/17 DETAILED RESULTS

Shag Estuary fine scale site boundaries

Shag Site A	1	2	3	4	Shag Site B	1	2	3	4
NZTM EAST	1428924	1428946	1428952	1428930	NZTM EAST	1428649	1428675	1428680	1428653
NZTM NORTH	4961364	4961346	4961361	4961375	NZTM NORTH	4961684	4961673	4961683	4961693

Fine scale station locations, Shag Estuary, 9 December, 2016

Shag Site A	1	2	3	4	5	6	7	8	9	10
NZTM EAST	1428925	1428932	1428939	1428945	1428948	1428941	1428936	1428930	1428932	1428938
NZTM NORTH	4961363	4961358	4961354	4961349	4961354	4961357	4961362	4961366	4961371	4961367
Shag Site B	1	2	3	4	5	6	7	8	9	10
NZTM EAST	1428651	1428660	1428668	1428676	1428675	1428668	1428660	1428653	1428654	1428661
NZTM NORTH	4961685	4961682	4961677	4961675	4961678	4961681	4961685	4961688	4961691	4961688

Shag Estuary sediment plate and peg locations and depth of plate (mm) below surface

Site A Sed Plates (Firm Muddy Sand)	NZTM East	NZTM North	Height/Depth (mm) 9 Dec 2016	Site B Sed Plates (Soft Mud)	NZTM East	NZTM North	Height/Depth (mm) 9 Dec 2016
Peg 1 (0m)	1428924	4961364		Peg 1 (0m)	1428649	4961684	
Plate 1 (2m)	1428922	4961364	-83	Plate 1 (2m)	1428650	4961686	-96
Plate 2 (4m)	1428923	4961366	-92	Plate 2 (4m)	1428650	4961688	-113
Peg 2 (5m)				Peg 2 (5m)			
Plate 3 (6m)	1428925	4961368	-80	Plate 3 (6m)	1428651	4961689	-113
Plate 4 (8m)	1428926	4961369	-101	Plate 4 (8m)	1428652	4961691	-78
Peg 3 (10m)				Peg 3 (10m)			

Water quality and subtidal sediment site locations, Shag Estuary, 9 December, 2016

Shag	Site X (lower)	Site Y (mid)	Site Z (upper)
NZTM EAST	1429424	1428683	1427239
NZTM NORTH	4961537	4962020	4962036

Sediment quality results, Shag Estuary (Sites X, Y and Z), Shag Estuary, 9 December, 2016

Year/Site	TOC	Mud	Sand	Gravel	TN	TP
	%				mg/kg	
Shag SED X 2016	<0.05	1.5	98.1	0.5	185	<500
Shag SED Y 2016	0.43	18.6	46.8	34.6	520	600
Shag SED Z 2016	0.22	1.8	14.6	83.6	420	<500

Redox Potential (mV) at fine scale sites, Shag Estuary, 9 December, 2016

Year/Site	Redox Potential (mV)				
	0cm	1 cm	3cm	6cm	10cm
2016 A	20	-7	-151	-165	-236
2016 B	-10	-138	-152	-214	-264

Appendix 2. 2016/17 Detailed Results (continued)

Physical and chemical results for fine scale Sites A and B, Shag Estuary, 9 December 2016

Year/Site/Rep	RPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg	TN	TP
	cm	ppt	%				mg/kg									
2016 A 1-4 [b]	3	31	0.17	24.3	72.7	2.9	0.013	8.5	3.3	5.6	4.5	27	10.3	0.011	<500	450
2016 A-4-8 [b]	3	31	0.17	15.7	80.7	3.6	0.015	8.7	3.4	5.9	4.7	27	11.5	0.016	<500	470
2016 A-9-10 [b]	3	31	0.18	17.2	78.8	3.9	0.018	8.9	3.3	5.8	4.7	27	11.1	0.017	<500	490
2016 B-1-4 [b]	3	32	0.35	25.6	61.2	13.2	0.025	9.8	5.3	8.2	5.9	37	15.6	0.033	600	610
2016 B-4-8 [b]	3	32	0.35	22.1	46.7	31.2	0.026	9.4	5.4	8.3	5.9	36	16.7	0.032	600	600
2016 B-9-10 [b]	3	32	0.34	21.2	47.8	31	0.021	9.5	5.2	8	5.7	35	16.9	0.03	500	650
ISQG-Low [a]	-	-	-	-	-	-	1.5	80	65	21	50	200	20	0.15	-	-
ISQG-High [a]	-	-	-	-	-	-	10	370	270	52	220	410	70	1	-	-

[a] ANZECC 2000. [b] composite samples.

Water quality results for Sites X, Y and Z, Shag Estuary, 9 December 2016

Parameter	Units	Shag Lower Site X (surface)	Shag Lower Site X (bottom)	Shag Mid Site Y (surface)	Shag Mid Site Y (bottom)	Shag Upstream Site Z (surface)	Shag Upstream Site Z (bottom)
Depth	m	0.1	0.63	0.1	0.75	0.1	0.8
Temperature	degrees C	16.8	16.58	16.9	16.9	17.7	16.3
Salinity	ppt	31.5	31.62	23.2	32.2	1.17	10.85
Dissolved Oxygen	mg/l	7.01	7.52	10.83	9.32	9.9	14.4
pH		8.32	8.36	8.5	7.8	8.23	8.7
Chlorophyll a	mg/m^3	0.1	0.8	1.5	30.8	0.5	227
Total Nitrogen	g/m^3	<0.3	<0.3	<0.3	0.5	0.4	3.1
Total Ammoniacal-N	g/m^3	0.021	0.023	0.017	0.036	0.02	1.7
Nitrite-N	g/m^3	<0.002	<0.002	<0.002	0.002	0.002	<0.002
Nitrate-N	g/m^3	0.01	0.01	0.006	0.014	0.102	<0.002
Nitrate-N + Nitrite-N	g/m^3	0.011	0.012	0.007	0.017	0.104	<0.002
Total Kjeldahl Nitrogen (TKN)	g/m^3	<0.2	<0.2	<0.2	0.5	0.3	3.1
Dissolved Reactive Phosphorus	g/m^3	0.01	0.012	0.006	0.015	0.01	0.119
Total Phosphorus	g/m^3	0.024	0.027	0.011	0.057	0.011	0.33

Epifauna abundance and macroalgal cover at fine scale sites, Shag Estuary, 9 December 2016

Group	Family	Species	Common name	Scale	Class	A	B
Topshells	Trochidae	*Diloma subrostrata*	Grooved topshell	#	ii	O	F
Red algae	Gracilariaceae	*Gracilaria* sp.	*Gracilaria* weed	%	ii	R	-
Green algae	Ulvaceae	*Ulva lactuca*	Sea lettuce	%	ii	R	-

Seagrass (*Zostera muelleri*) and macroalgal cover and biomass at fine scale sites, Shag Estuary, 9 December 2016

Year/Site	Seagrass Biomass and Cover ($g.m^{-2}$ wet weight (%)	Macroalgal Biomass and Cover $g.m^{-2}$ wet weight (%)
2016 A	0 (0%)	10 (<5%)
2016 B	0 (0%)	10 (<5%)

Appendix 2. 2016/17 Detailed Results (continued)

Infauna results for fine scale Sites A and B, Shag Estuary, 9 December 2016

Infauna (numbers per 0.01327m² core)

Group	Species	NZ Hyb AMBI	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	B-01	B-02	B-03	B-04	B-05	B-06	B-07	B-08	B-09	B-10
POLYCHAETA	*Boccardia syrtis*	2	4	2	5	3	1	5			1				1							
	Glycera lamelliformis	3	1																			
	Heteromastus filiformis	3	1	1	1		2	1				1										
	Nereididae *(unid. juveniles)*	3								1		2	1				1				1	1
	Paradoneis sp.#1	3	58	50	37	53	30	30	33	4	10	17						1	2	1		4
	Perinereis vallata	2											1		1	1			2		1	1
	Prionospio aucklandica	2		1				1		1									1			
	Scolecolepides benhami	4	12	4	6	3	5	10	6		2	1	3	5	3	2	4	1	4	7	13	3
	Scoloplos cylindrifer	1								1												
GASTROPODA	*Cominella glandiformis*	3						1					1					2		1		
BIVALVIA	*Arthritica* sp.#1	4	1																			
	Austrovenus stutchburyi	2		1	1		1	1	4	1	3	3							1	2		
	Tellina liliana	2								1												
CRUSTACEA	Copepoda sp.#1	2	1																			
	Hemiplax hirtpes	5										1	1							1		
	Paracorophium excavatum	4	145	195	145	174	104	113	133	101	55	89	41	53	20	17	13	14	25	18	23	10
Total individuals in sample			**223**	**254**	**195**	**233**	**143**	**162**	**176**	**110**	**71**	**114**	**48**	**58**	**25**	**20**	**18**	**18**	**35**	**30**	**38**	**19**
Total number of species in sample			**8**	**7**	**6**	**4**	**6**	**8**	**4**	**7**	**5**	**7**	**5**	**2**	**4**	**3**	**3**	**4**	**6**	**6**	**3**	**4**

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		NZ Hyb AMBI Gp*	Details
Polychaeta	*Boccardia syrtis*	2	A small surface deposit-feeding spionid. Prefers low mud content but found in a wide range of sand/mud. It lives in flexible tubes constructed of fine sediment grains, and can form dense mats on the sediment surface. Very sensitive to organic enrichment and usually present under unenriched conditions.
	Glycera lamelliformis	3	Glyceridae (blood worms) are predators and scavengers. They are typically large, and are highly mobile throughout the sediment down to depths of 15cm. They are distinguished by having 4 jaws on a long eversible pharynx. Intolerant of anoxic conditions and low salinity.
	Heteromastus filiformis	3	Small sized capitellid polychaete. A sub-surface, deposit-feeder that lives throughout the sediment to depths of 15cm, and prefers a muddy-sand substrate. Shows a preference for areas of moderate organic enrichment as other members of this polychaete group do. Mitochondrial sulfide oxidation, which is sensitive to high concentrations of sulfide and cyanide, has been demonstrated in this species.
	Nereididae	3	Active, omnivorous worms, usually green or brown in colour. There are a large number of New Zealand nereids. Rarely dominant in numbers compared to other polychaetes, but they are conspicuous due to their large size and vigorous movement. Nereids are found in many habitats. The tube-dwelling nereid polychaete Nereis diversicolor is usually found in the innermost parts of estuaries and fjords in different types of sediment, but it prefers silty sediments with a high content of organic matter. Blood, intestinal wall and intestinal fluid of this species catalyzed sulfide oxidation, which means it is tolerant of elevated sulphide concentrations.
	Paradoneis sp. 1	3	Slender burrowing worms that are probably selective feeders on grain-sized organisms such as diatoms and protozoans.
	Perinereis vallata	2	An intertidal soft shore nereid (common and very active, omnivorous worms). Prefers mud/sand sediments. Prey items for fish and birds. Sensitive to large increases in sedimentation.
	Prionospio aucklandica	2	Common at low water mark in harbours and estuaries. A surface deposit-feeding spionid that prefers living in muddy sands but is very sensitive to changes in the level of silt/clay in the sediment (Norkko et al. 2001)
	Scolecolepides benhami	4	A spionid, surface deposit feeder. Is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark. A close relative, the larger Scolecolepides freemani occurs upstream in some rivers, usually in sticky mud in near freshwater conditions. e.g. Waihopai Arm, New River Estuary.
	Scoloplos cylindrifer	1	Originally, *Haploscoloplos cylindrifer.* Belongs to Family Orbiniidae which are thread-like burrowers without head appendages. Common in intertidal sands of estuaries. Long, slender, sand-dwelling unselective deposit feeders. Pollution and mud intolerant.
Gastropoda	*Cominella glandiformis*	3	Endemic to NZ. A very common carnivore living on surface of sand and mud tidal flats. Has an acute sense of smell, being able to detect food up to 30 metres away, even when the tide is out. Intolerant of anoxic surface muds.
Bivalvia	*Arthritica* sp. 1	4	A small sedentary deposit feeding bivalve. Lives greater than 2cm deep in the muds. Sensitive to changes in sediment composition.
	Austrovenus stutchburyi	2	Family Veneridae bivalves are very sensitive to organic enrichment. Cockles are suspension feeders with a short siphon - live a few cm deep at mid-low water situations. Responds positively to relatively high levels of SS for short period; long term exposure has adverse effects. Small cockles are an important in diet of wading bird species; In typical NZ estuaries, cockle beds are most extensive near the mouth of an estuary and become less extensive (smaller patches surrounded by mud) moving away from the mouth. Near the upper estuary in developed catchments they are usually replaced by mud flats and in the north patchy oyster reefs, although cockle shells are commonly found beneath the sediment surface. Although cockles are often found in mud concentrations greater than 10%, they struggle. Cockles improve sediment oxygenation, increasing nutrient fluxes and influencing the type of macroinvertebrate species present (Lohrer et al. 2004, Thrush et al. 2006).

Appendix 3. Infauna Characteristics (continued)

Group and Species		NZ Hyb AMBI Gp*	Details
Bivalvia	*Tellina liliana*	2	A deposit feeding wedge shell. This species lives at depths of 5–10cm in the sediment and uses a long inhalant siphon to feed on surface deposits and/or particles in the water column. Rarely found beneath the RPD layer. Adversely affected at elevated suspended sediment concentrations.
Crustacea	Copepoda sp. 1	2	Copepods are a group of small crustaceans found in the sea and nearly every freshwater habitat and they constitute the biggest source of protein in the oceans. Usually having six pairs of limbs on the thorax. The benthic group of copepods (Harpactacoida) have worm-shaped bodies.
	Hemiplax hirtpes	5	The stalk-eyed mud crab is endemic to NZ and prefers waterlogged areas at the mid to low water level. Makes extensive burrows in the mud. Tolerates moderate mud levels. This crab does not tolerate brackish or fresh water (<4ppt). Like the tunnelling mud crab, it feeds from the nutritious mud. Previously *Macrophthalmus hirtipes*.
	Paracorophium exca-vatum	4	A tube-dwelling corophioid amphipod. Two species in NZ, *Paracorophium excavatum* and *Paracorophium lucasi* and both are endemic to NZ. *P. lucasi* occurs on both sides of the North Island, but also in the Nelson area of the South Island. *P. excavatum* has been found mainly in east coast habitats of both the South and North Islands. Sensitive to metals. Also very strong mud preference.
	Hemiplax hirtpes	5	The stalk-eyed mud crab is endemic to NZ and prefers waterlogged areas at the mid to low water level. Makes extensive burrows in the mud. Tolerates moderate mud levels. This crab does not tolerate brackish or fresh water (<4ppt). Like the tunnelling mud crab, it feeds from the nutritious mud. Previously *Macrophthalmus hirtipes*.

* NZ AMBI Biotic Index sensitivity groupings sourced from Robertson et al. (2015).
1 = highly sensitive to (intolerant of) mud and organic enrichment;
2 = sensitive to mud and organic enrichment;
3 = widely tolerant of mud and organic enrichment;
4 = prefers muddy, organic enriched sediments;
5 = very strong preference for muddy, organic enriched sediments.